Best Available Copy

AD-782 222

HIGH-EFFICIENCY, SINGLE-FREQUENCY LASER AND MODULATOR STUDY

R. C. Ohlmann, et al

Lockheed Missiles and Space Company, Incorporated

Prepared for:

Office of Naval Research
Advanced Research Projects Agency

30 June 1973

AD-782 222

HIGH-EFFICIENCY, SINGLE-FREQUENCY LASER AND MODULATOR STUDY

Ninth Quarterly Technical Report

N-JY-71-18 30 June 1973

R. C. Ohlmann, K. K. Chow
J. J. Younger, W. B. Leonard, and J. Kannelaud

ARPA Order No. 306
Expiration Date: 31 December 1973
Amount: $399,684

Contract No. N00014-71-C-0049
Program Code 421
Effective Date of Contract: 1 September 1970

Scientific Officer: Director, Physics Programs
Physical Sciences Division
Office of Naval Research, Arlington, Va. 22217

Principal Investigator: R. C. Ohlmann (415) 493-4411, Ext. 45275

Sponsored by

Advanced Research Projects Agency

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessaryil representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U.S. Government.

LOCKHEED PALO ALTO RESEARCH LABORATORY
LOCKHEED MISSILES & SPACE COMPANY INC
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

Section 1
INTRODUCTION

The work described in this report is the final year's effort of a three-year program to study wide bandwidth laser communications at 1.06-μm wavelengths. Earlier efforts of this program (during the first two years) were directed to studying the means to produce a high-efficiency, single-frequency neodynium doped yttrium aluminum garnet (Nd:YAG) laser operating at 1.06-μm, and to produce high-efficiency octave-bandwidth microwave light modulators for this wavelength (Refs. 1 and 2). In addition, a study was also made of laser communication configurations that were suitable for very high data rates. The overall objective of this year's program, then, is to apply the results of these earlier studies to assemble a laboratory communication system that uses the entire modulation bandwidth available. In particular, the final result of this program is to be a laboratory demonstration of a laser-communication system having a bandwidth of 2 GHz.

The detailed objectives of this study program are as follows:

(1) Design a laboratory communication system, using 1.06-μm radiation from a Nd:YAG laser and having a system bandwidth of 2 to 4 GHz

(2) Assess the state-of-the-art of high-frequency photodetectors, with emphasis on a cross-field photomultiplier tube (PMT), that offer good frequency and spectral response and are suitable as the receiver elements of this communication demonstration

(3) Define and design the necessary microwave, digital-modulation and frequency-modulation subsystems for the communication system

(4) Assembly and operate the various subsystems

(5) Demonstrate and evaluate the system performance in a laboratory environment

During this quarter, objectives (1), (2) and (3) have basically been accomplished. All required components for this laboratory demonstration are now on order. In addition, further improvement of the optical modulation has been made.

Section 2
SYSTEM DESIGN

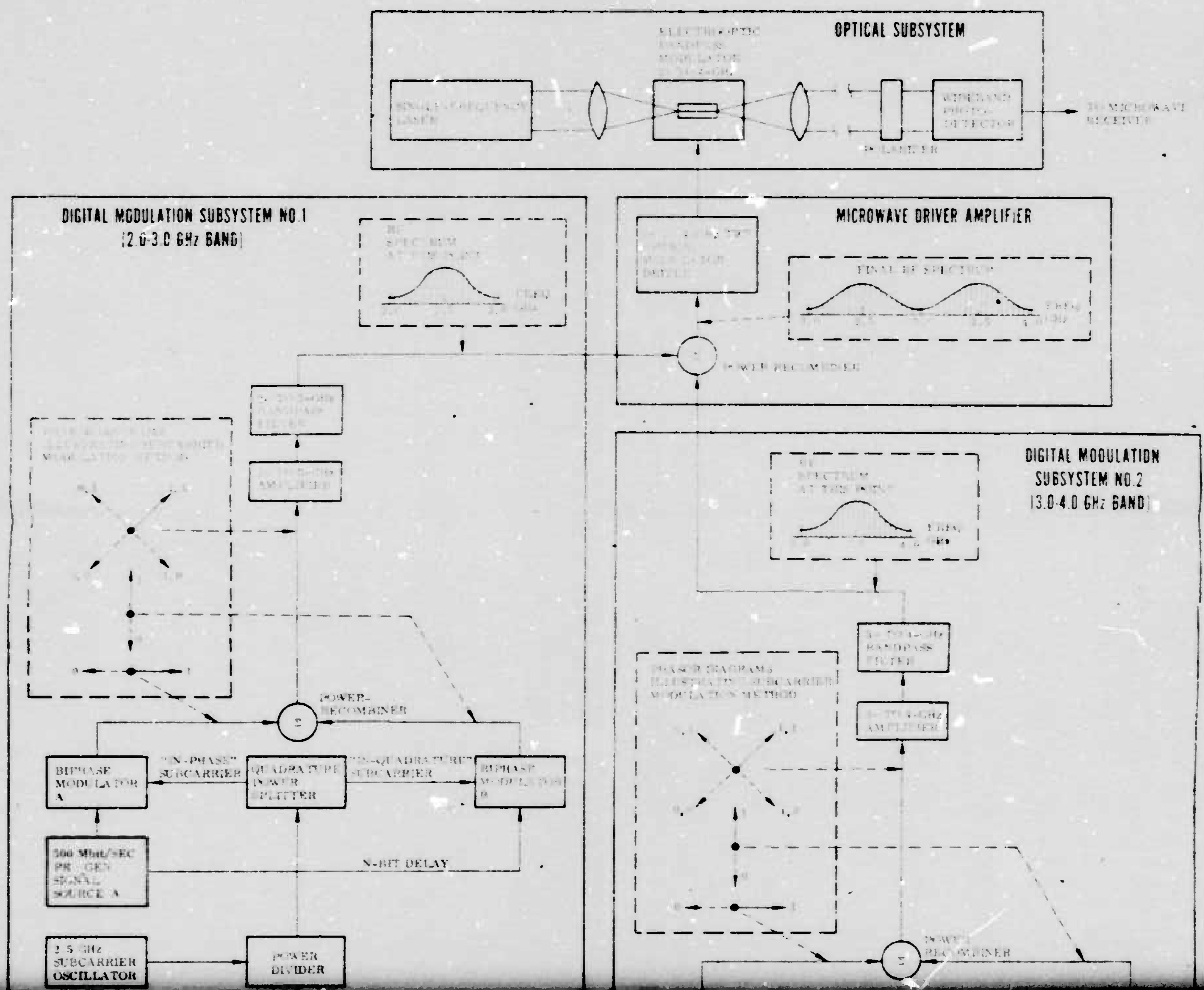
2.1 MODULATION FORMATS AND BANDWIDTH CONSIDERATIONS

To transmit data at the high rates desired, microwave subcarrier modulation formats are chosen. That is, the information to be transmitted is first modulated onto a microwave carrier frequency (the subcarrier), which, in turn, is modulated onto the optical beam (the optical carrier). For a given modulation format, the data rate to be transmitted determines the required system bandwidth. Therefore, for this demonstration, the data rate has to be chosen so that the entire available microwave bandwidth of the optical modulator is used.

During the first quarter, efforts have been concentrated on the use of quadriphase-shift-keying (QPSK) modulation of digital signals. Two microwave subcarriers are chosen, one at 2.5 GHz, the other at 3.5 GHz. Two streams of pseudo random digital data, at 500 Mbit/sec per stream, are modulated on to each subcarrier. Thus a total data at a 2-Gbit/sec rate will be modulated onto the microwave subcarriers. The complex microwave signals will then occupy the entire bandwidth of 2 to 4 GHz. Such choice of subcarriers and modulation rates are purely for convenience so that laboratory demonstration of feasibility can be made as soon as possible.

2.2 QUADRIPHASE-SHIFT-KEYING DIGITAL MODULATION

Detailed block diagrams of this laboratory laser-communication system using QPSK modulation format to transmit a 2-Gbit/sec data stream is shown in Figs. 2-1 and 2-2. The optical subsystem, the digital modulation subsystems, and the modulator driver are shown in Fig. 2-1. The microwave receiver, which amplifies the output of the photodetector, and the subsequent digital demodulation subsystems are shown in Fig. 2-2. The optical subsystem is self-explanatory; the laser and the modulator


OPTICAL SUBSYSTEM
DIGITAL MODULATION SUBSYSTEM NO.1
(2.0-3.0 GHz BAND)
MICROWAVE DRIVER AMPLIFIER
FINAL RF SPECTRUM
DIGITAL MODULATION
SUBSYSTEM NO.2
(3.0-4.0 GHz BAND)
POWER-
RECOMBINER
BIPHASE
MODULATOR
A
"IN-PHASE"
SUBCARRIER
QUADRATURE
POWER
SPLITTER
"IN-QUADRATURE"
SUBCARRIER
BIPHASE
MODULATOR
B
500 Mbit/SEC
SIGNAL
SOURCE A
N-BIT DELAY
2.5 GHz
SUBCARRIER
OSCILLATOR
POWER
DIVIDER
PHASOR DIAGRAMS
ILLUSTRATING SUBCARRIER
MODULATION METHOD

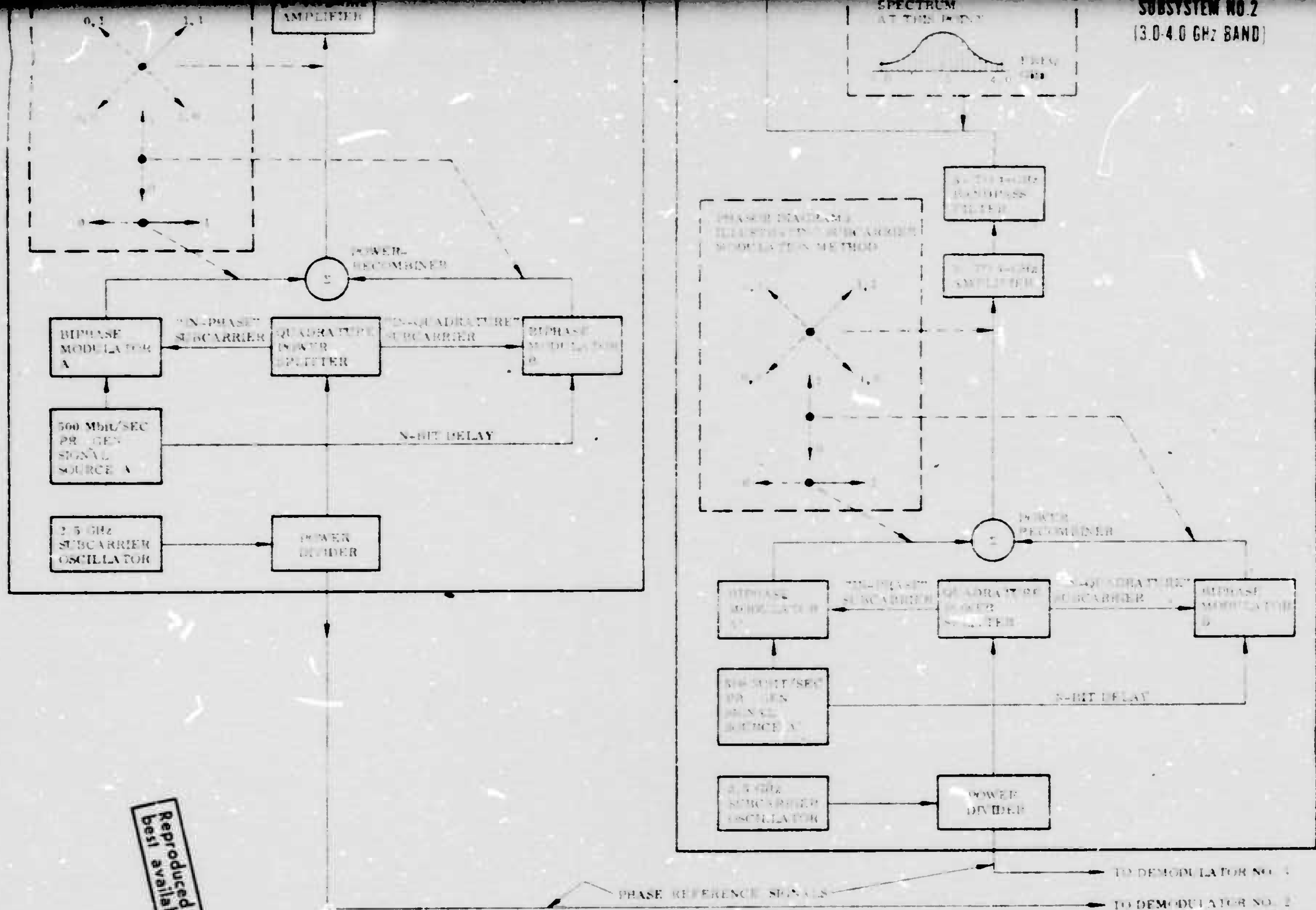
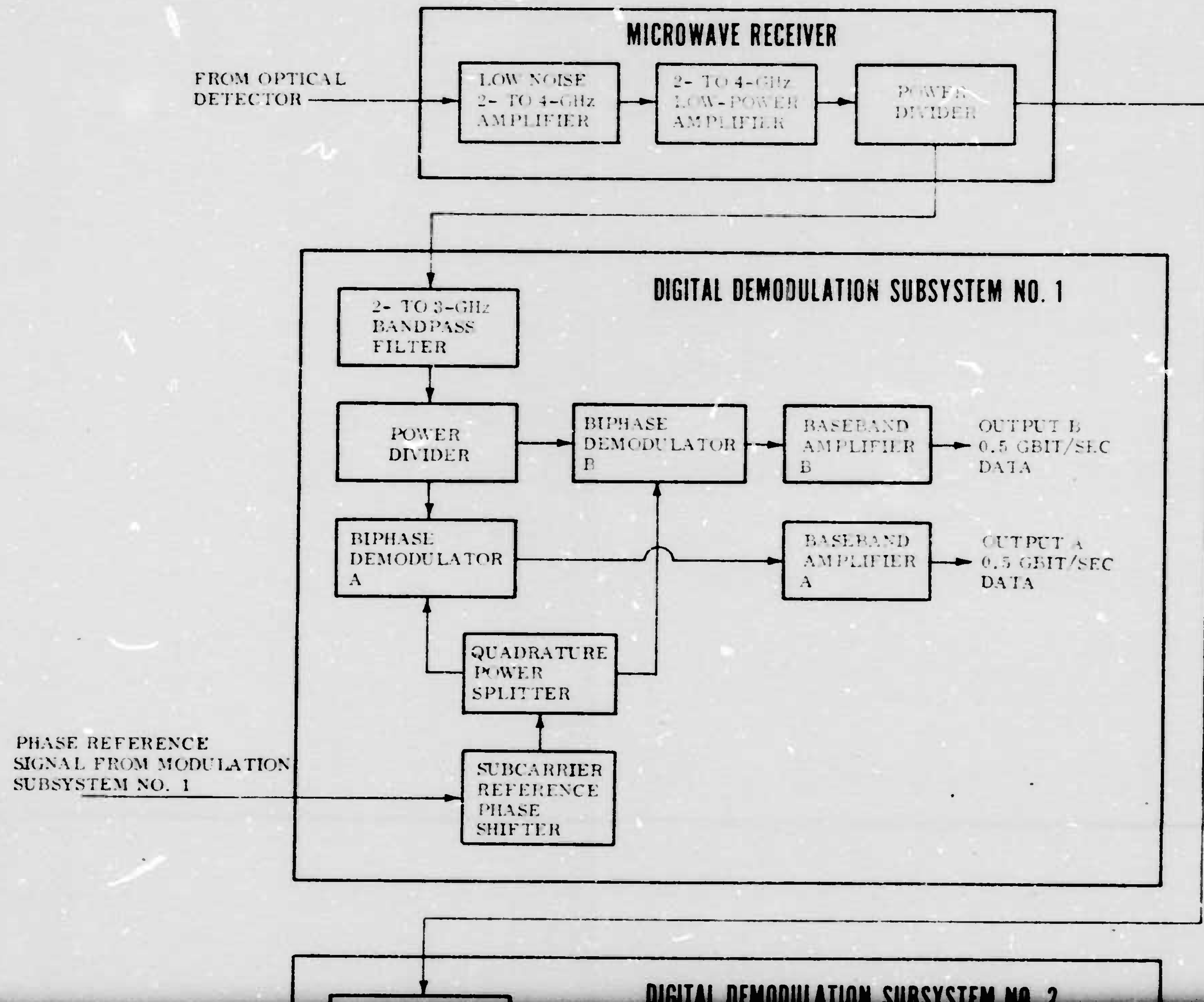


Fig. 2-1 [illegible]-Gbits/sec La[illegible]atory Laser Communication System: Optical [illegible]system and Transmitter Electr[illegible]


MICROWAVE RECEIVER
FROM OPTICAL DETECTOR
LOW NOISE 2- TO 4-GHz AMPLIFIER
2- TO 4-GHz LOW-POWER AMPLIFIER
POWER DIVIDER
DIGITAL DEMODULATION SUBSYSTEM NO. 1
2- TO 3-GHz BANDPASS FILTER
POWER DIVIDER
BIPHASE DEMODULATOR B
BASEBAND AMPLIFIER B
OUTPUT B 0.5 GBIT/SEC DATA
BIPHASE DEMODULATOR A
BASEBAND AMPLIFIER A
OUTPUT A 0.5 GBIT/SEC DATA
QUADRATURE POWER SPLITTER
SUBCARRIER REFERENCE PHASE SHIFTER
PHASE REFERENCE SIGNAL FROM MODULATION SUBSYSTEM NO. 1
DIGITAL DEMODULATION SUBSYSTEM NO. 2

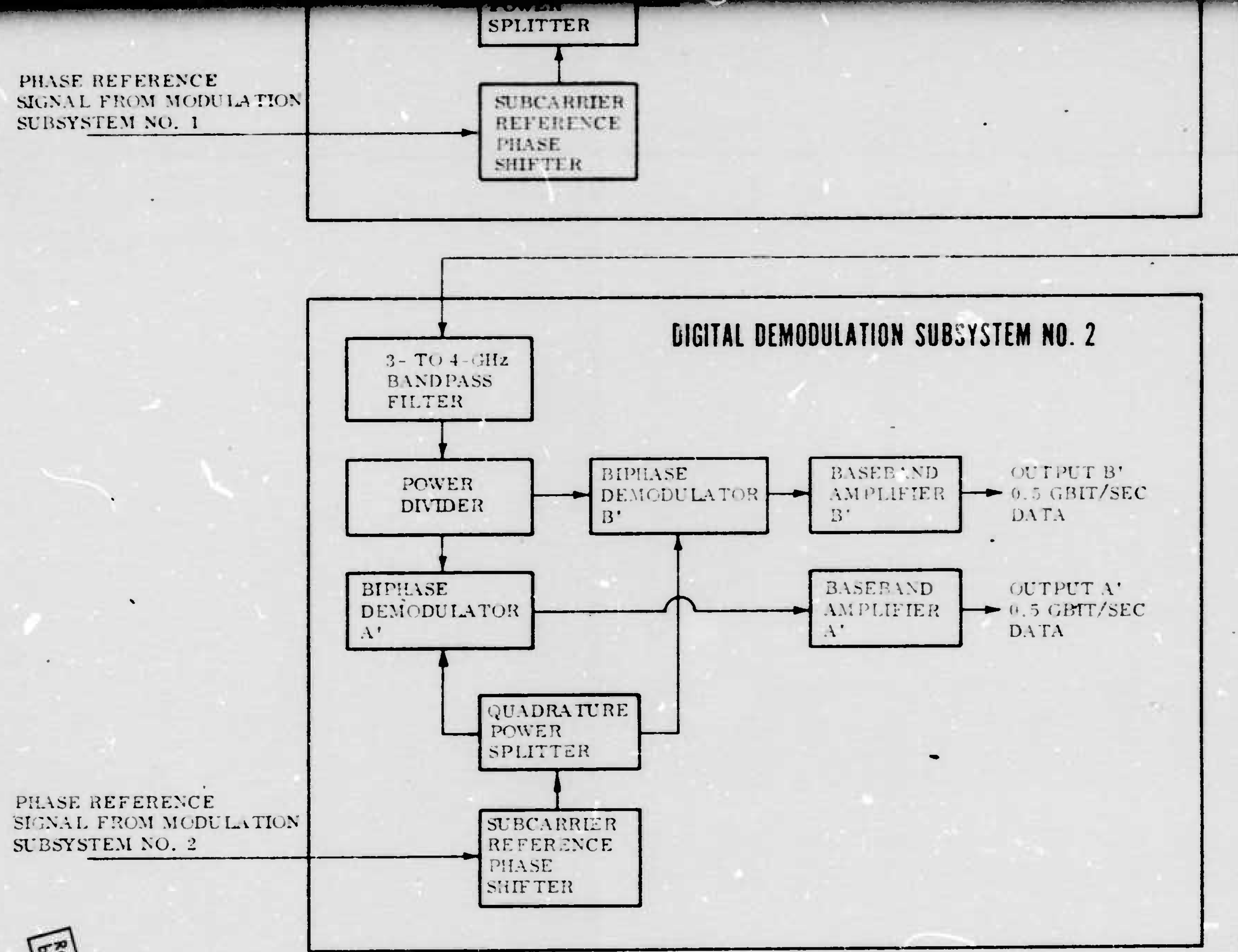


Fig. 2-2 2-Gbits/sec Laboratory Laser Communication System: Receiver Electronics

were both developed under this contract in an earlier phase. The photodetector, however, is a commercial one and will be procured under this contract.

In such a digital QPSK modulation subsystem, a cw microwave signal is used as a subcarrier. Modulation of the subcarrier by the digital data results in a change of the rf phase of the subcarrier. These are shown in detail in the phasor diagram presented in Fig. 2-1. Two subcarriers are chosen: one at 2.5 GHz, and the other at 3.5 GHz. Each subcarrier is split into two channels: one "in-phase" channel and one "in-quadrature" channel. Each of the channels is then biphased shifted at a biphase modulator by an independent 500-Mbit/sec simulated data stream from a pseudo-random (PN) signal generator as shown in the associated phasor diagram in Fig. 2-1. That is, the phase of the microwave subcarrier of that channel is reversed at each change of state of the signal at the binary input terminal of the biphase modulator. Thus, if the modulating signal is a binary "1", the phase of that channel is undisturbed. If, on the other hand, the modulator signal is a binary "0", the phase of that channel is reversed (switched by 180 electrical deg. as shown dotted in the phasor diagram).

Since the two channels are already in quadrature, the two biphase modulators will give four possible quadrature phase relationships. Therefore, the combination of the two channels results in the final phasor relationship shown in Fig. 2-1 and gives a total data rate of 1 Gbits/sec for that subband.

At an input data rate of 1-Gbits/sec, the sideband power of QPSK modulation has first nulls at 500 MHz above and below the subcarrier frequency. Outside the first nulls, the power content is negligible. Therefore, for each subband, the center frequency of the subband is chosen as the subcarrier frequency (2.5 and 3.5 GHz as mentioned earlier), and a 1-GHz bandpass filter (2 to 3 GHz and 3 to 4 GHz) is used to reject the sideband power outside the first nulls. Combination of these two subbands gives a total data rate of 2 Gbits/sec. This is amplified by a 10-W traveling-wave tube (TWT) to drive the optical modulator.

In the photodetector, the optical carrier is detected to recover the microwave subcarriers and their sidebands which are then sent to the first amplifier in the receiver subsystem. After amplification, the microwave signal is divided into two halves as shown in Figure

2-2. Each half is filtered to give one of the subbands which is then further divided into two channels. The signal in each channel together with a strong "in-phase" or "in-quadrature, reference are directed to a biphase demodulator. In a communication system, the reference signals required are normally derived from the incoming signals. For the ease of this demonstration, however, the reference signals are taken from the transmitter directly by separate cables (hardwire references) to demonstrate the capacity of the laser communication system, without having to deal with the added complications of phased-locked loops, etc. for the derivation of the reference signals. These hardwire references are clearly indicated in Figs. 2-1 and 2.2 The outputs of the biphase modulator, after proper low-pass filtering, gives the recovered digital data streams.

It should be emphasized here that although the 500-Mbits/sec PR signals for both channels in the subband are synchronous as used here in the demonstration, this system will accept synchronous data with only minor degradation. This has been demonstrated in an earlier experiment conducted at LMSC (Ref. 3).

Section 3

CRITICAL COMPONENTS AND SYSTEM IMPLEMENTATION

3.1 THE OPTICAL MODULATOR

During the first quarter, additional effort were spent in improving the 2- to 4-GHz electrooptic modulator, since this modulator is the heart of this demonstration. Much improvement has been obtained, as reported in the following paragraphs.

After the approaches were initiated last year, the "reverse-flow" mode of operation was investigated further. This is the mode in which the rf drive power for the optical modulator flows through the circuit in such a way that the electrooptic modulating crystal is at the input digit. Previous work had rendered rather unsatisfactory results (Ref. 2) in terms of frequency response and modulation efficiency (modulation index/unit drive power/unit modulation bandwidth). During the past few months, through painstaking tuning and matching procedures, improved performance over the "forward-flow" mode was obtained, as shown in Fig. 3-1. At the 6-W input drive level, an average of 60 percent modulation index across a 3-dB bandwidth of 2.07 to 4.00 GHz is obtained. This is a definite improvement over the "forward-flow" mode obtained last year, shown in Fig. 3-2 as a comparison, for which approximately 62 percent average modulation index was obtained at about a 10-W drive level.

It appears from Fig. 3-1 that the modulator was tuned to a higher passband than the desired 2 to 4 GHz, because the low-frequency end showed a sharp drop while the high-frequency end showed uniform response to the band-edge. Therefore, additional tuning efforts will be made during the next quarter to center the frequency band.

3.2 PN SIGNAL GENERATORS

In the digital modulation subsystem, the simulated data streams are provided by two 500-Mbit/sec pseudorandom (PR) signal generators. A convenient way of producing

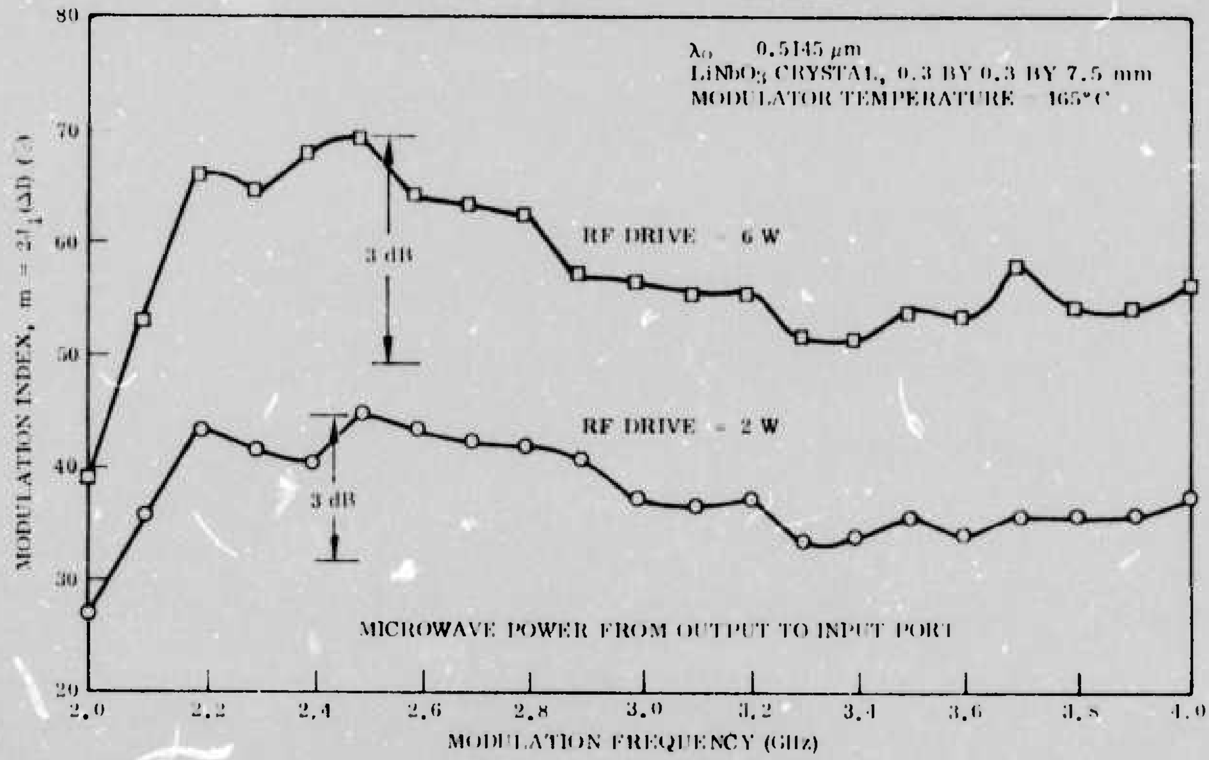


Fig. 3-1 Modulation Index Versus Frequeney for 7.5-mm-Length $LiNbO_3$ Crystal With rf Power in Reverse Direction

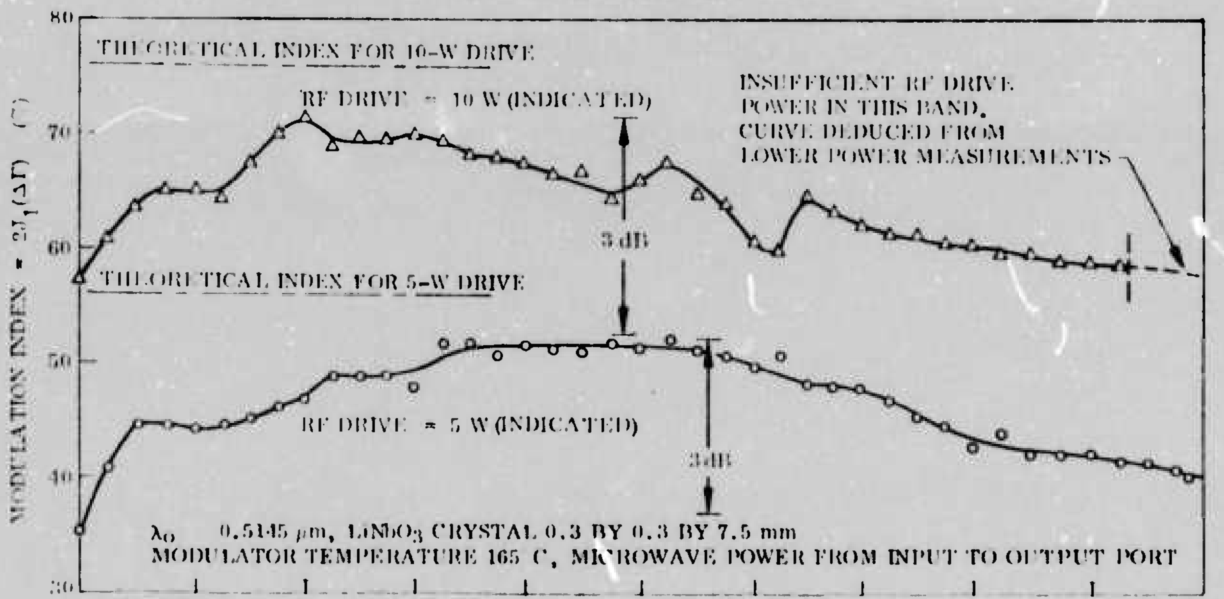


Fig. 3-2 Modulation Index Versus Frequency for 7.5-mm-Length $LiNbO_3$ Crystal With rf Power in Forward Direction. (Results were obtained last year and are included here for purpose of comparison)

a 500-Mbit/sec PR signal stream is to combine the output of a 250-Mbit/sec maximal length PR signal generator. Such a generator produces a $2^{11} - 1$ (= 2047) bit binary word. Since maximal length signals separated by more than 1 bit are uncorrelated, two remote taps from this PR generator can be used to produce a $2^{12}-2$ (= 4094) bit word at 500 Mbit/sec by interleaving the signals at the taps.

The 500-Mbit/sec PR generators of this kind have been fabricated at LMSC through our Independent Research efforts. The 2047-bit-length PR signals were produced by using an 11-stage feedback shift register. Good response time was obtained by using a hybrid integrated circuit MOD-2 adder and buffers as shown in Fig. 3-3. The rise times of the signals from the 250-Mbit/sec PR generator were improved by the dual hybrid buffer. The hybrid MOD-2 adder constructed the 500-Mbit/sec word, and the final hybrid buffer squared up the rise and fall-times. Laboratory measurement shows that the rise and fall-times are all subnanosecond and there is no incomplete bit. In the laboratory demonstration, the output from such a 500-Mbit/sec generator is used to modulate either a 2.5-GHz or a 3.5-GHz subcarrier by means of a biphase modulator.

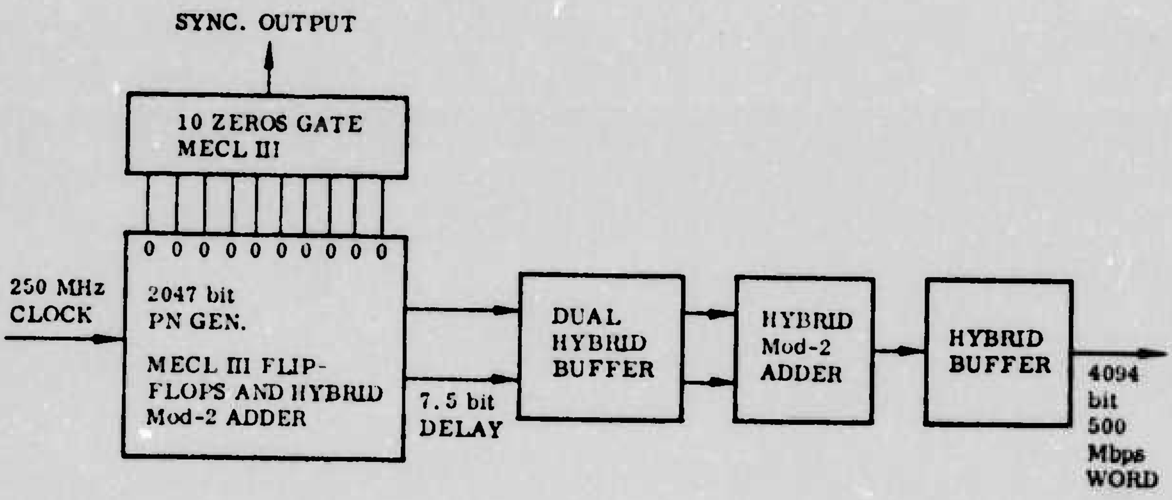


Fig. 3-3 Block Diagram of a 500-Mbits/Sec Word Generator

3.4 SYSTEM IMPLEMENTATION

The system implementation will be essentially a hardware copy of the block diagrams shown in Figs. 2-1 and 2-2. Judicious choice of amplifiers and attenuators will have to be determined to ensure proper signal levels so that signal-to-noise ratios are maximized and cross-talks are minimized. Initial work has already been started on system implementation.

Section 4
FUTURE PLANS

For the next quarter, additional effort will be spent to improve the performance of the optical moduiator still further. The main effort, however, will be to complete the implementation of the 2-Gbit/sec digital system so that an interim laboratory demonstration can be made by the end of the second quarter. After this interim laboratory demonstration, efforts will be concentrated in implementing a 1-GHz analog and a 1-Gbit/sec digital data transmission system.